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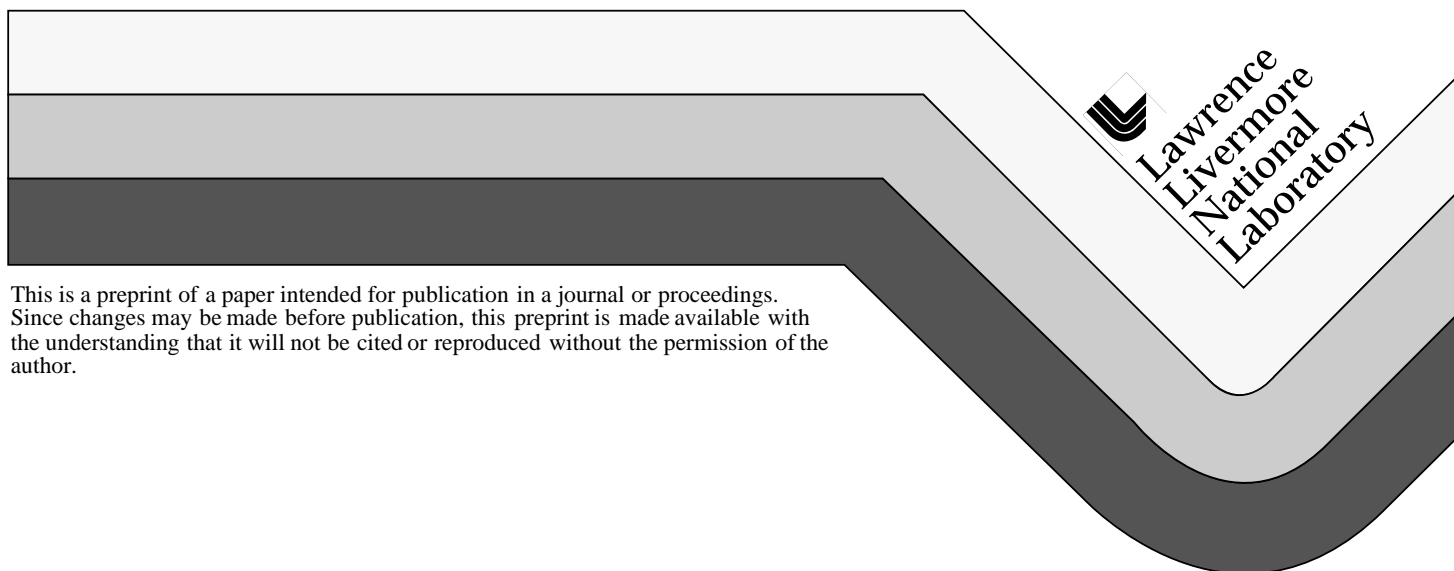
PREPRINT

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Paul A. Urtiew
Jerry W. Forbes
Craig M. Tarver
Frank Garcia

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Calibration of Manganin Pressure Gauges at 250°C*

Paul A. Urtiew, Jerry W. Forbes, Craig M. Tarver and Frank Garcia

*Lawrence Livermore National Laboratory
P.O.Box 808, L-282
Livermore, CA 94551*

Abstract. During the past several decades manganin gauges have been used extensively for making in-situ high pressure measurements in materials under dynamic loading conditions. Prior to their use manganin gauges were calibrated but only under normal ambient temperatures. Recent interest in the behavior of both reactive and inert materials, when they were subjected to dynamic loading while being at high initial temperature, required a re-visit of the calibration procedure and reconfirmation of the gauges' proper behavior in such an extreme thermal environment. The paper describes the procedure of making such new calibrations of the existing manganin gauges and reports on the new findings. The Hugoniot for 6061-T6 aluminum at 250°C is also given.

INTRODUCTION

One of the concerns in today's work with energetic materials is their safety when they are exposed to extreme environmental conditions. Hazard scenarios can involve multiple stimuli, such as heating to temperatures close to the thermal explosion conditions followed by fragment impact, producing a shock in the hot explosive. This scenario has been studied for triaminotrinitrobenzene (TATB)-based insensitive explosive under various thermal and confinement conditions (1-3) and for LX-04, an HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)-based solid high explosive (4,5). In all our studies (1, 2, 4, 5, 6) we used embedded manganin pressure gauges and reactive flow calculations to study the change in the behavior of the material

when it is subjected to the above insult. While manganin is believed to be insensitive to changes in temperature (7) and in our previous tests, manganin gauges were found to perform normally even in a very high temperature regime (250°C), it was deemed necessary to perform a more rigorous calibration of the gauges when they are exposed to such a severe thermal environment. This study was conducted with 6061-T6 aluminum, which is well behaved under these conditions. It is the material used for impact flyers and buffers in initiation experiments on preheated high explosives (HE's). The aluminum helps to distribute heat across the HE that is against the front and back buffers.

EXPERIMENT

The experiments were performed in our 100 mm diameter (4") propellant driven gas gun, capable of accelerating a 1 kg projectile to a

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velocity of 2.5 km/s. The target assembly, which was common for these tests, is shown in Fig. 1. A

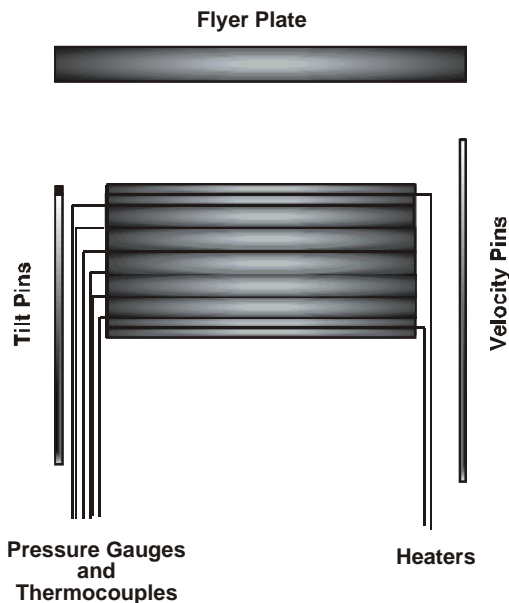


Figure 1. Target assembly for the 4" gas gun experiments

12.5 mm thick aluminum plate, 90 mm in diameter is mounted on the sabot to provide the impact on the front surface of the target assembly. A heater foil is embedded between the two 3 mm thick Al buffer plates which were placed in front of and behind the five 5 mm thick Al discs serving as the inert test sample assembly. Six gauge stations were placed into the assembly between the discs as shown in the figure. The gauge package consisted of the standard 4-lead manganin pressure gauge and 5 mil (125 μm) Teflon armor on both sides of the gauge to enhance its survivability and to insulate it from the conductive medium. Physical dimensions of the gauge are shown in Fig. 2. Nine thermocouples were also placed at various places in the gauge stations to monitor the temperature of the whole test assembly. The heating was done at the rate of 1.5°C per minute and the shot was fired when the temperature within the whole assembly was within a few degrees from the desired temperature of 250°C.

The experimental value of the linear thermal expansion coefficient for 6061-T6 Al was

$2.48 \cdot 10^{-5} / ^\circ\text{C}$ (8) which is within 0.8% of the value listed in the CRC Engineering Handbook (9) for aluminum. Expansion coefficient of $1 \cdot 10^{-4} / ^\circ\text{C}$ was used for Teflon (9).

GAUGE CALIBRATION CHECK FOR AMBIENT CONDITIONS

Similar targets were also tested under ambient conditions without the heaters and the thermocouples. The resulting Us-Up data for 6061-T6 aluminum agreed very well with the

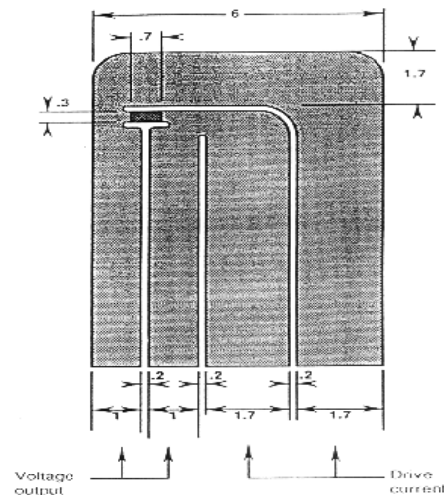


Figure 2. Physical dimensions of the manganin pressure gauge. All dimensions are in mm.

LASL Handbook data given in Ref. (10). The manganin gauge pressure value using the published calibration (Eq. 2 in Ref. 11) for the peak initial shock pulse also agreed with the pressure calculated from the Us-Up data.

Results of the ambient shots are illustrated in Fig. 3, which shows both the pressure profiles at six different gauge stations as well as the time-space diagram of the process as the wave propagates through the target assembly. LASL Handbook data given in Ref. (10). The manganin gauge pressure value using the published calibration (Eq. 2 in Ref. 11) for the peak initial shock pulse also agreed with the pressure calculated from the Us-Up data.

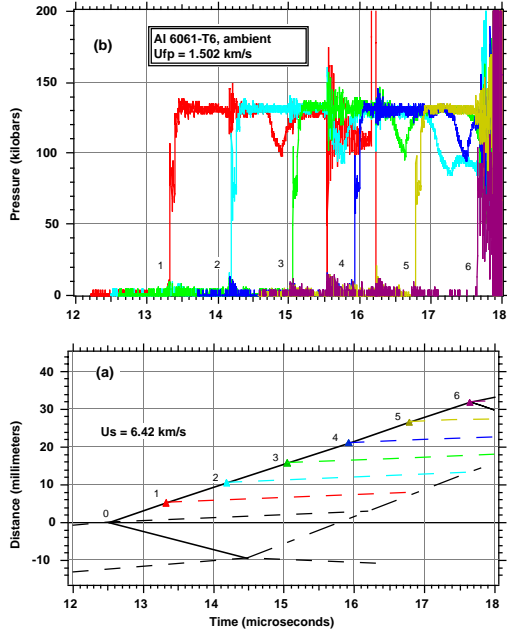


Figure 3. Ambient experiment.
(a) – Time space diagram of the wave train generated by the impact of the flyer plate on the target assembly.
(b) – Pressure profiles as recorded by all six gauges as they were hit by the shock wave.

EFFECT OF HEATING

The whole target consisted of 6061-T6 Al plates and gauge packages, which consisted of manganin foil (25 μm) and Teflon armor 125 μm thick on each side of the gauge foil. While each gauge package is only around 1/3 of a mm thick, the total of six such packages amount to about 5% of the whole target assembly.

Shock velocities were determined by dividing the thickness of aluminum plates by the shock transit time between the gauge elements which was corrected for the shock transit time through the Teflon armor of the gauge package. This correction for the hot experiments was based on the Hugoniot of Teflon at 250°C, which was calculated using a Grueneisen equation of state with Grueneisen coefficient divided by volume and specific heat assumed constant. The particle velocity in aluminum was derived from the intersection of the cold Aluminum flyer (P-Up) adiabat with the new ρU_s line from the origin for the heated material. This resulted in a new U_s -Up relationship for heated 6061-T6 aluminum at 250°C as $U_s = 4.863 + 1.702 U_p$.

RESULTS

Four preheated experiments were performed with the projectile velocity of 0.665, 1.222, 1.523 and 1.744 km/s. Pressure traces from one of the experiments is shown in Fig. 4. This figure shows

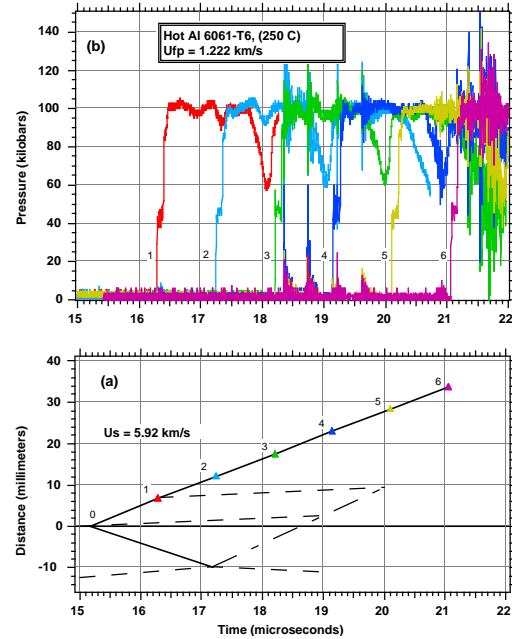


Figure 4. Hot experiment at $T_0=250^\circ\text{C}$.
(a) – Time space diagram of the wave train generated by the impact of the flyer plate on the target assembly.
(b) – Pressure profiles as recorded by all six gauges as they were hit by the shock wave.

pressure records obtained at the six gauge stations. The time-space diagram below it illustrates the wave train generated by the impact and the shock propagation through the test assembly. The wave train was calculated with the new EOS for the hot Aluminum and thermal expansion of the heated sample taken into account. Figure 5 illustrates the agreement between the hot and cold (P-Up) values determined from U_s and projectile velocity and the experimental manganin gauge data. Table 1 shows the summary of all six tests. Two of these tests were done at ambient conditions.

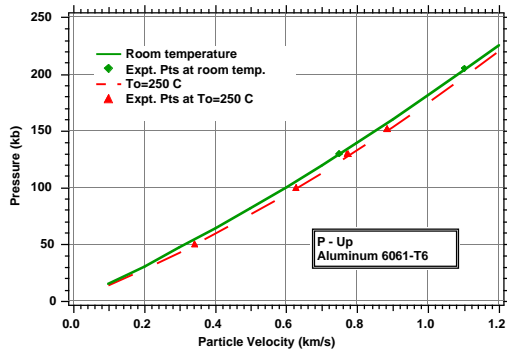


Figure 5. Pressure – particle velocity plane showing both the cold and hot adiabat with the experimental points.

CONCLUSIONS

Even though the records are rather noisy, they show pressures within 1 % of the values obtained from the measured U_s, U_p values. That shows that the manganin gauge performance has not changed and that manganin itself is insensitive to changes of initial temperature up to 250°C.

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TABLE 1. Comparison of Manganin Gauge Performance under Normal (room) and High (250°C) Initial Temperatures.

| Shot No | To (°C) | Ufp (km/s) | Expected P (kb) | Obtained P (km/s) | Deviation (%) |
|---------|------------|---------------|-----------------------|-------------------------|------------------|
| 4508 | 25 | 2.210 | 204.2 | 211 | 3.3 |
| 4509 | 25 | 1.502 | 129.0 | 131 | 2.3 |
| 4503 | 250 | 0.665 | 49.9 | 50 | 0.2 |
| 4504 | 250 | 1.523 | 127.8 | 130 | 1.72 |
| 4505 | 250 | 1.744 | 150.3 | 152 | 1.13 |
| 4510 | 250 | 1.222 | 98.8 | 100 | 1.25 |